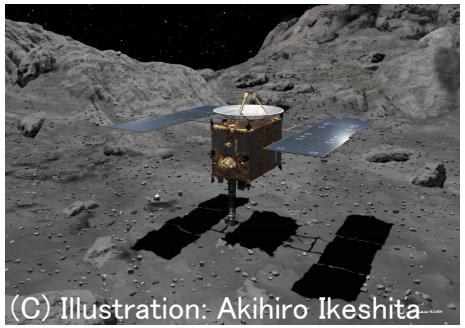
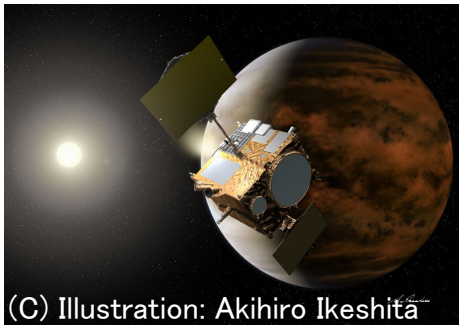
Empowered by Innovation





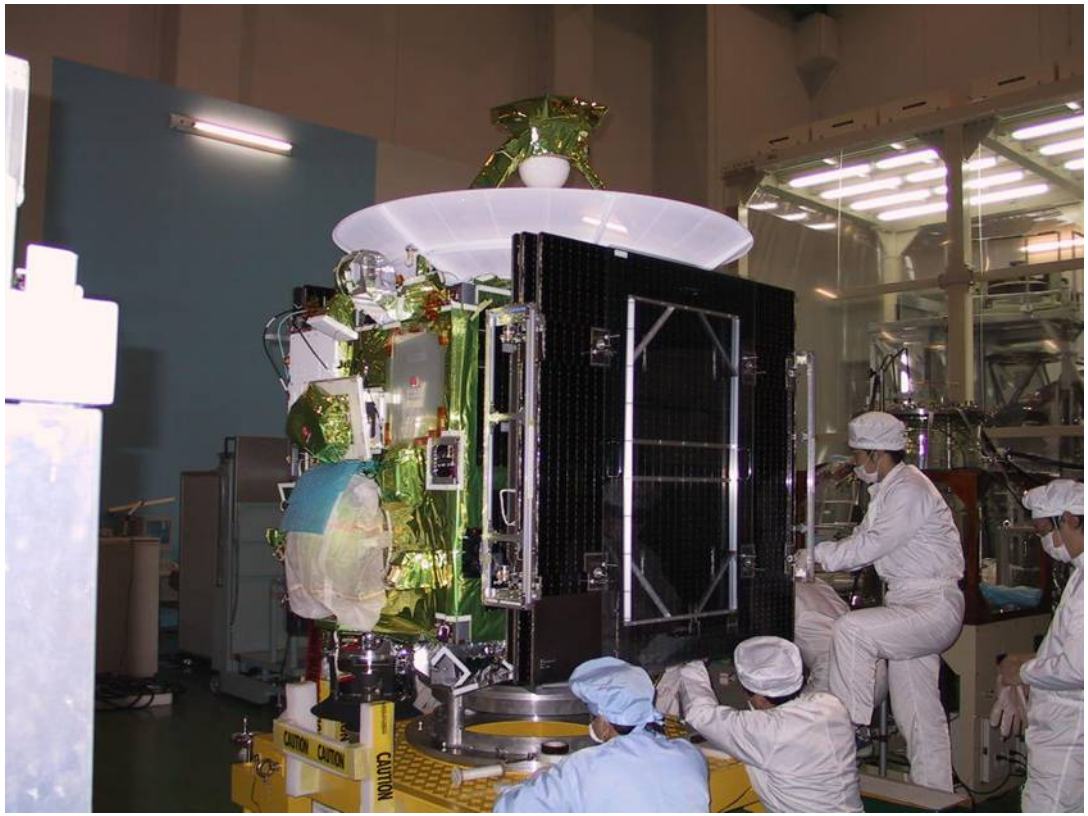
Mission Success for the Planetary Exploration Spacecraft

NEC Corporation
Asteroid Explorer “Hayabusa” System manger /
Venus Climate Orbiter “Akatsuki” Project Manager
Takeshi Oshima

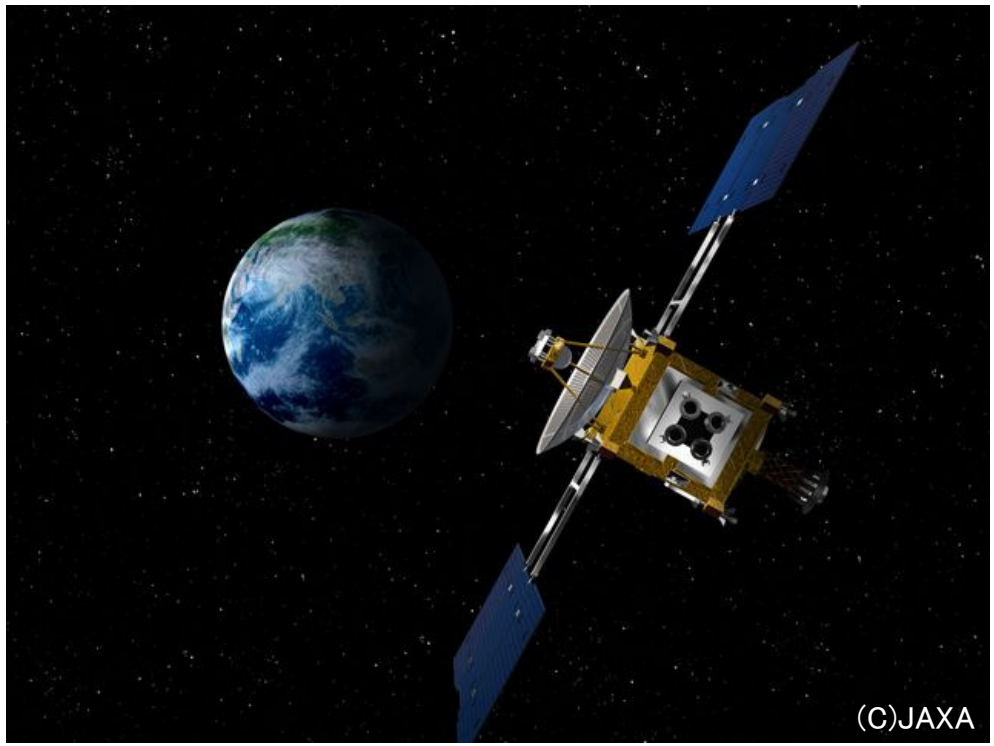
Asteroid Explorer “Hayabusa”

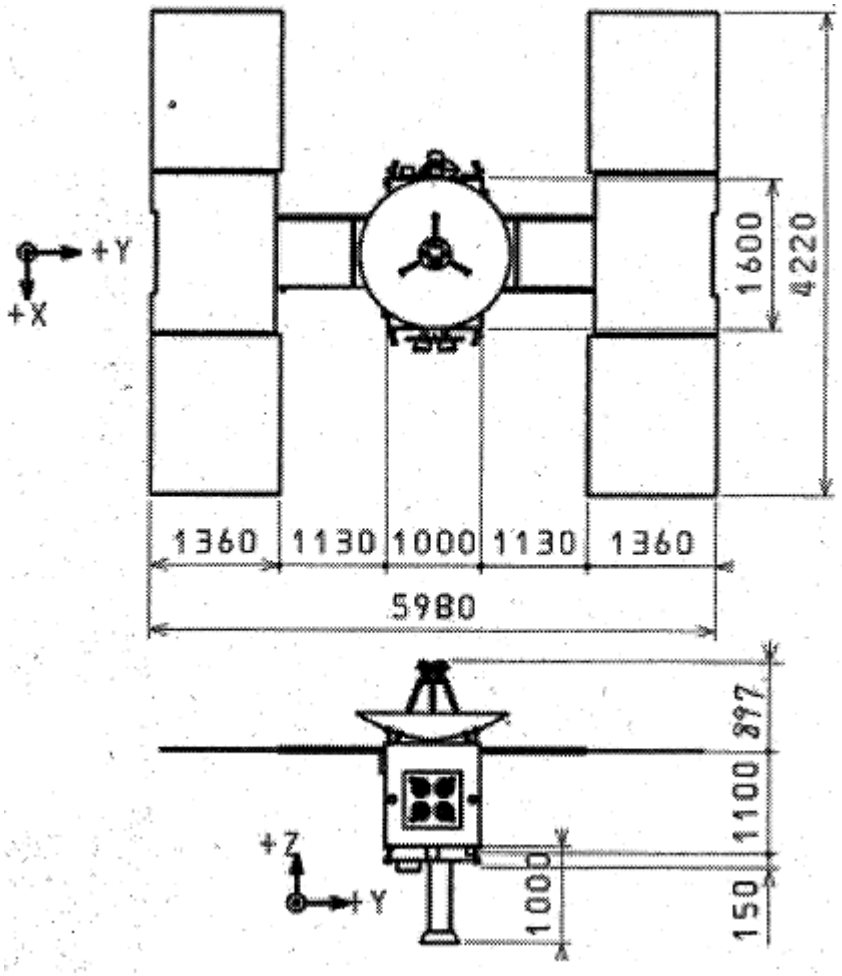
Japan Aerospace Exploration Agency (JAXA) has launched Asteroid Explorer “Hayabusa” on May 9th, 2003.

NEC had designed, manufactured and tested “Hayabusa” as the system integrator.



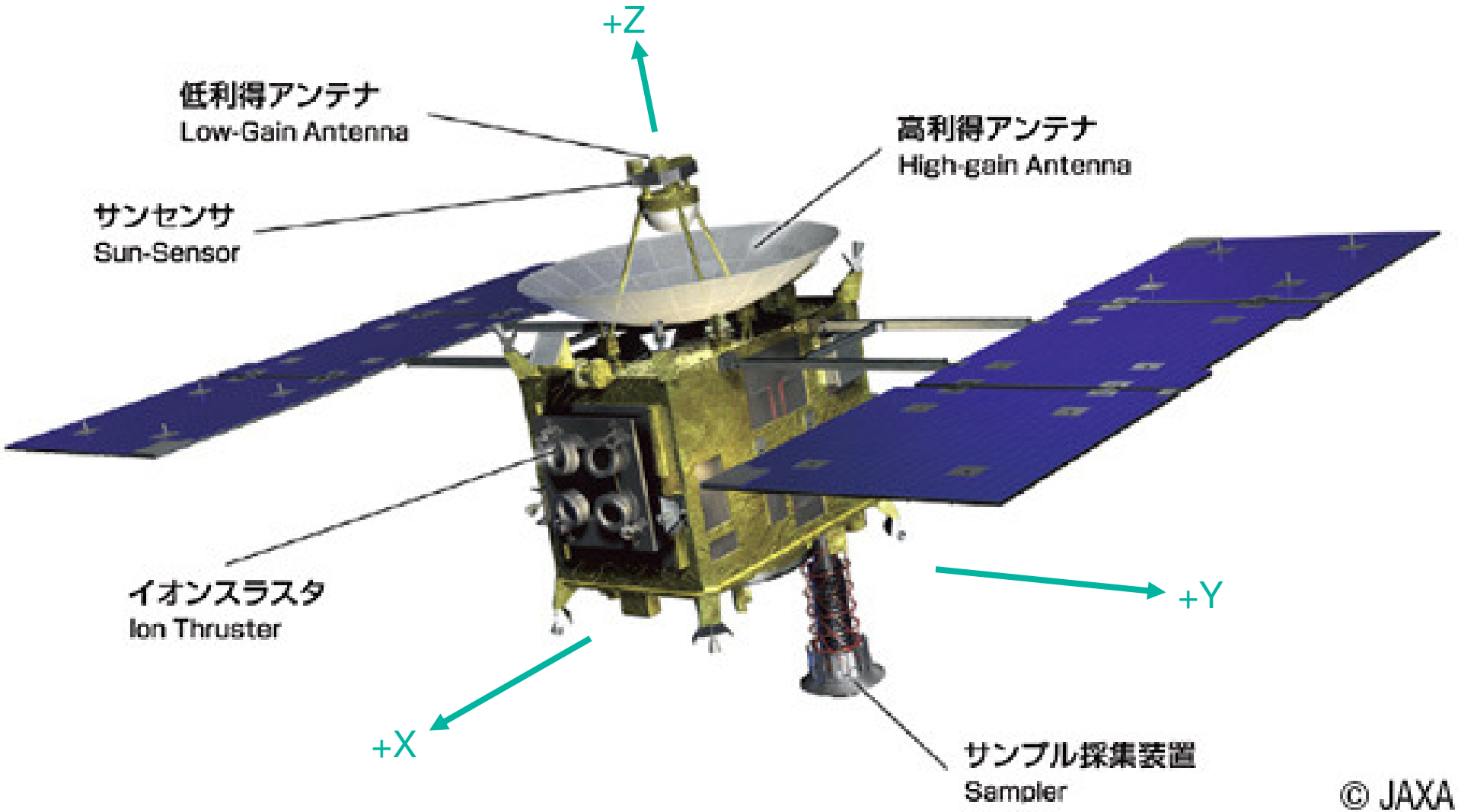
Size of “Hayabusa” Spacecraft



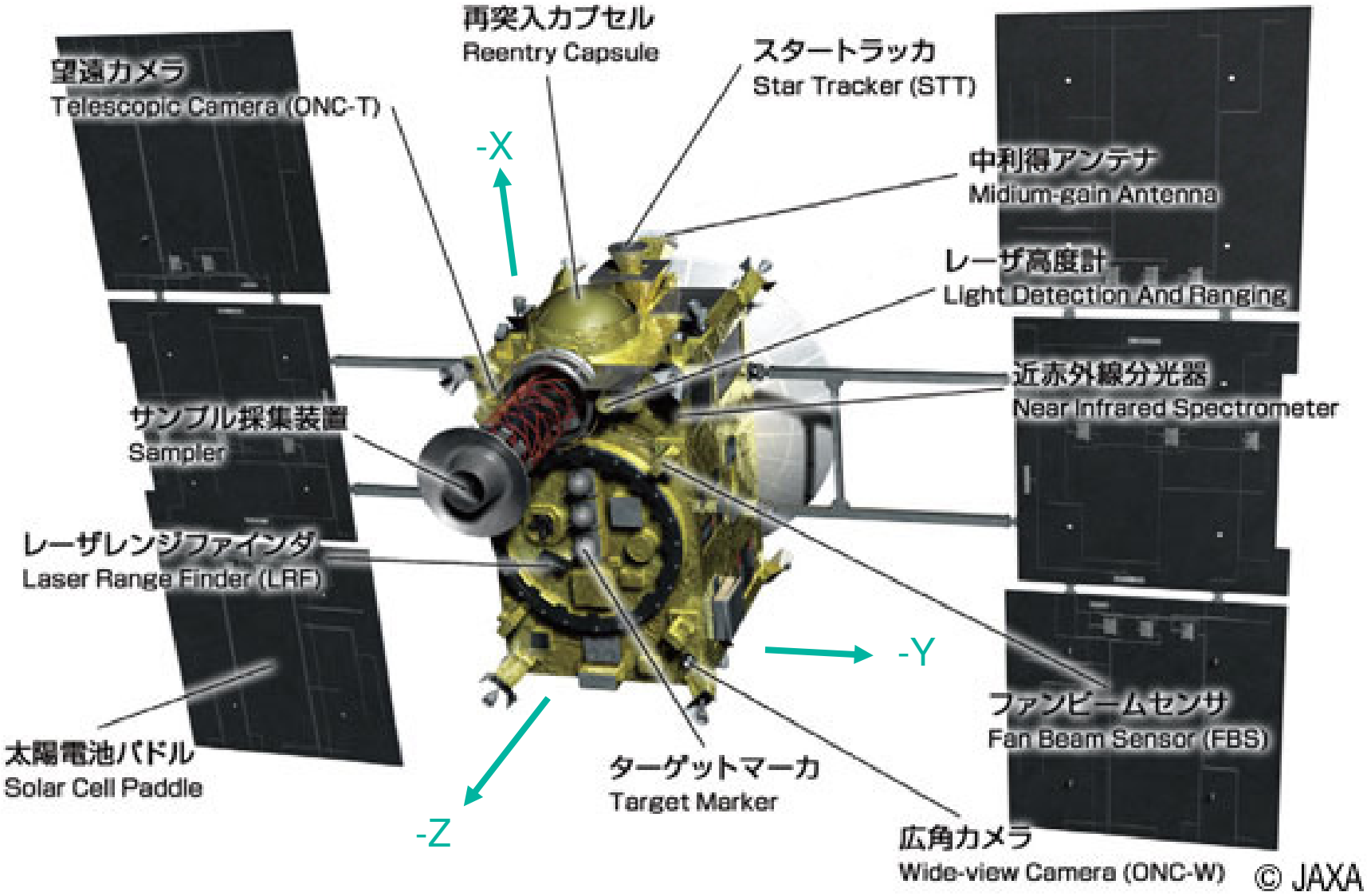


Mass：510kg@Launch

Configuration of Hayabusa Spacecraft (1/2)



Configuration of Hayabusa Spacecraft (2/2)



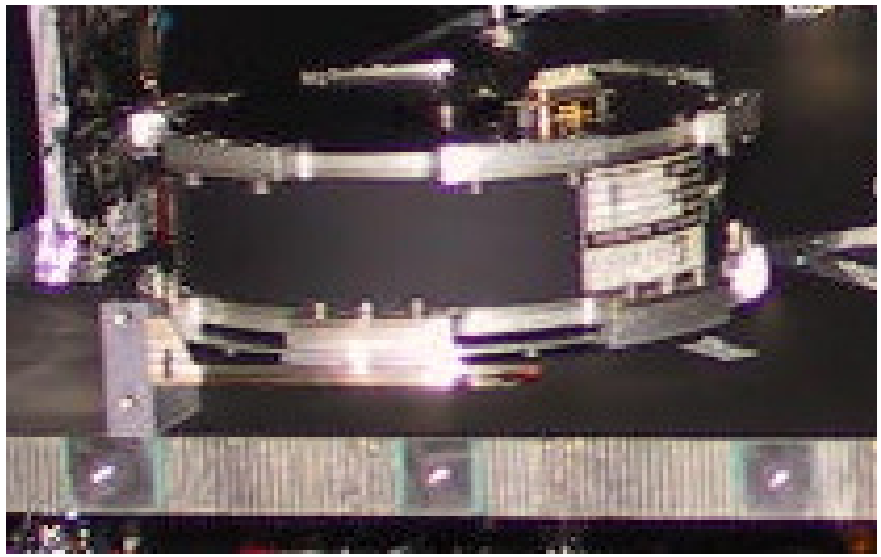
“HAYABUSA” survived seven challenges!

1. RW-X Fail
2. RW-Y Fail
3. Unexpected Shape of Itokawa
4. RCS Leak
5. Communication Down
6. BAT Over Discharge
7. Ion Engine System degradation

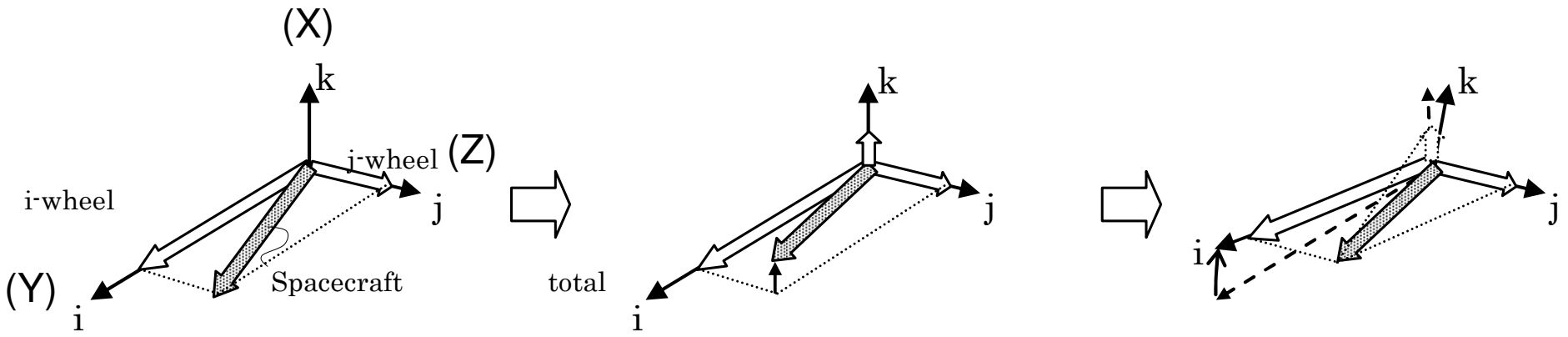
RW: Reaction Wheel
RCS: Reaction Control System
BAT: Battery

<No.1> RW-X Fail

- Date: July 31st, 2005
- Cause: Delamination of an aluminum liner (added for Hayabusa)
- Results: RW-X Fail
- Recovery Method: DRW (Dual RW) Mode (prepared in advance)
- Lessons Learned: “Improvement” shall be paid attention very carefully, even if it is minor.



1-1 DRW Logic



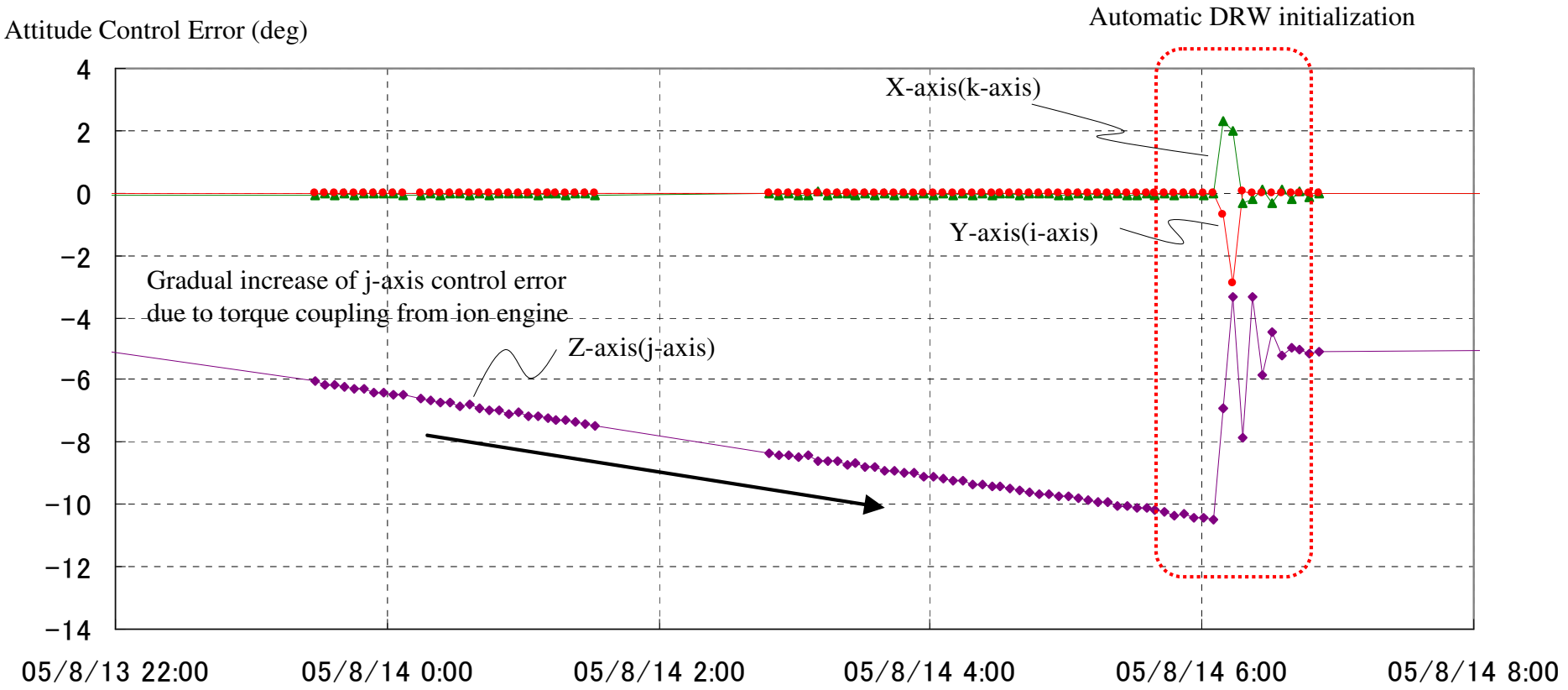
Total momentum is maintained by i- and j-axis wheels.

As k-axis momentum increases, the spacecraft begin nutation.

As a consequence of nutation damping, j-axis rotates so that total momentum is held by i- and j- wheel momentum again.

- HGA (High Gain Antenna) and LIDAR (Light Detection And Ranging) are aligned parallel to Z-axis -> Error around Z is allowable.
- Error around Z-axis is adjusted periodically by RCS.

1-2 Automatic DRW initialization

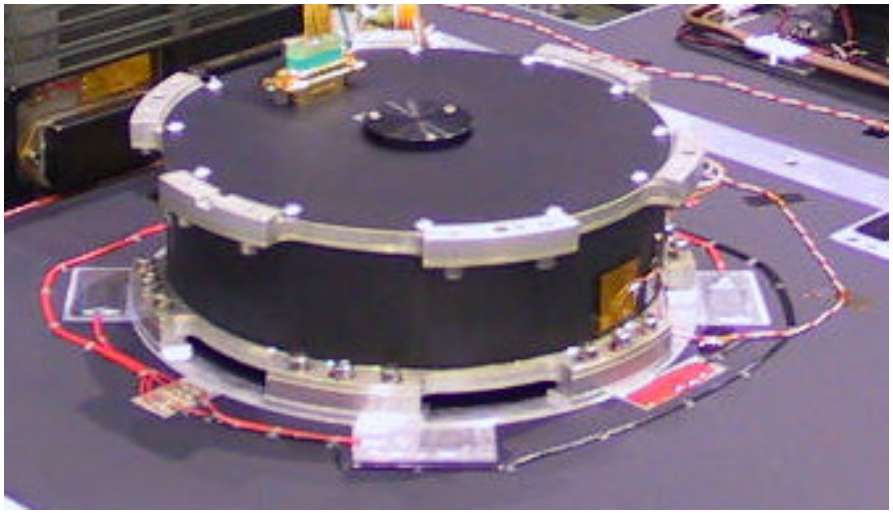


<No.2> RW-Y Fail

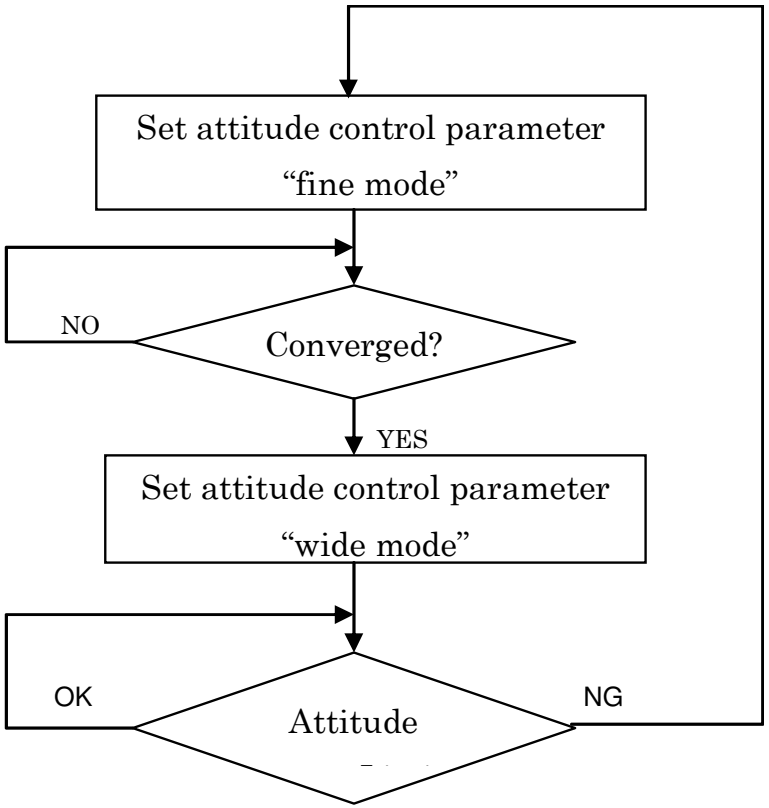
- Date: October 3rd, 2005
- Cause: Delamination of an aluminum liner (again)
- Results: RW-Y Fail -> Safe Hold Mode
- Recovery Method: RCS Control
  - FNI (Free Nutation Initiation)
  - AMT (Angular Momentum Trimming)
- Lessons Learned: Where there is a will, there is a way.

Newly Developed

Newly Developed



2-1 Attitude control by FNI & AMT



FNI Control Flow

- Expand Attitude Control Range:
  - HGA Link/Observation: +/-0.7 deg
  - MGA Link: +/-3.0 deg
  - No Link: +/-5.0 deg
- Shorten the pulse width of RCS:
  - 15ms -> 6~8ms
- FNI (Free Nutation Initiation)
  - Refer to the left figure.
  - At the "wide mode", S/C nutate freely (in order to save RCS propellant)
- AMT (Angular Momentum Trimming):
  - Control the angular momentum of S/C by the short RCS pulse at the appropriate spin phase.

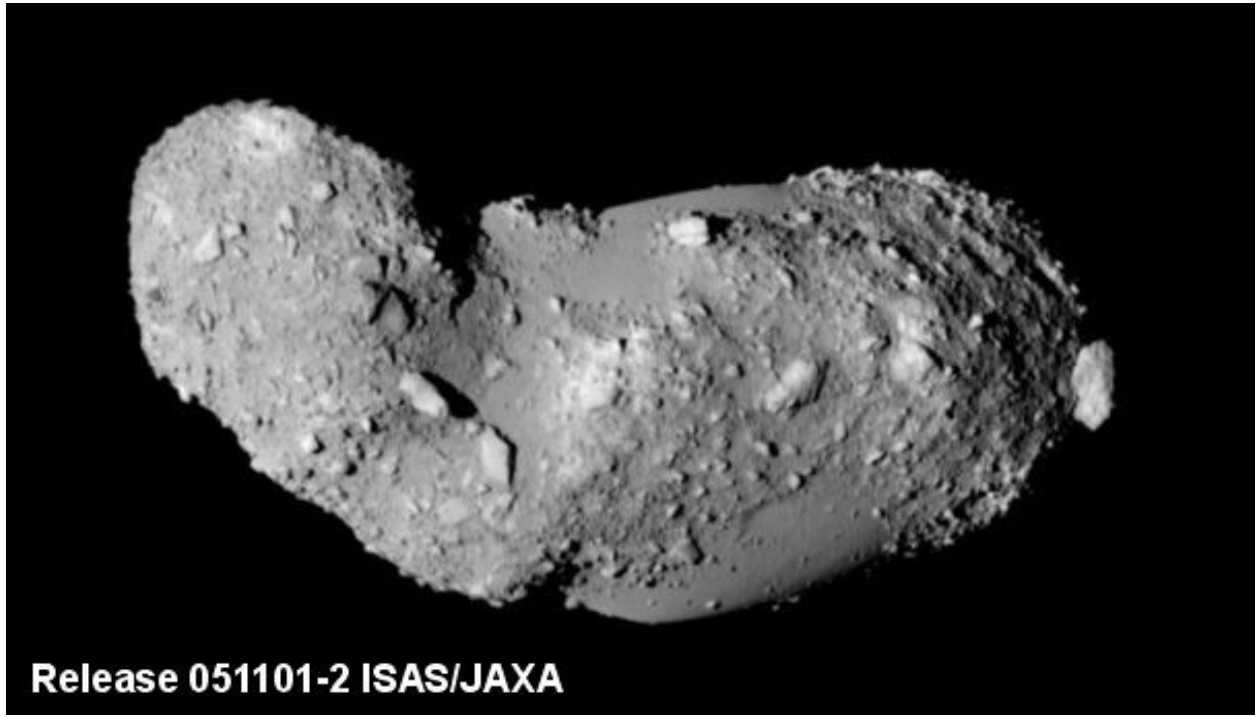
<No.3> Unexpected Shape of Itokawa

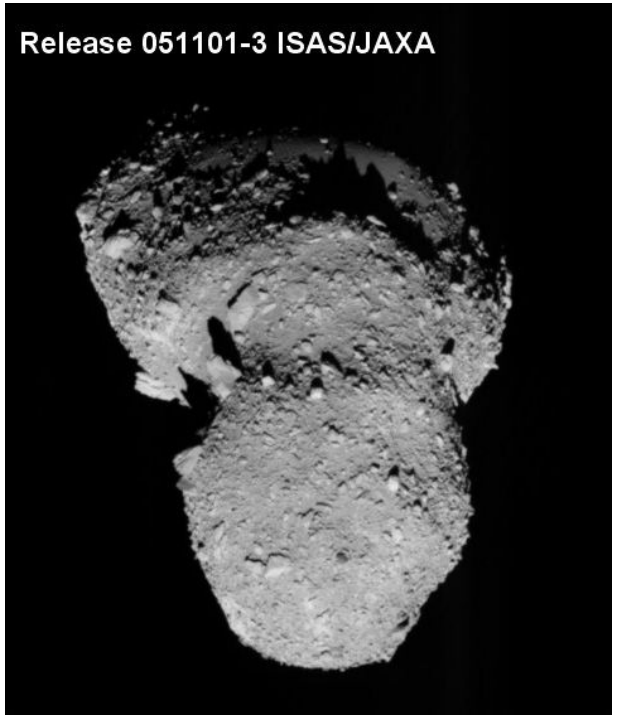
GCP: Ground Control Points
NAV: Navigation

- Date: November 4th,2005 (Touch Down Rehearsal 1)
- Cause: Unexpected Shape of Itokawa
- Results: Fail of autonomous descending
- Recovery Method: GCPNAV + Delta-V Simulator
- Lessons Learned: Strength of a compact and active team

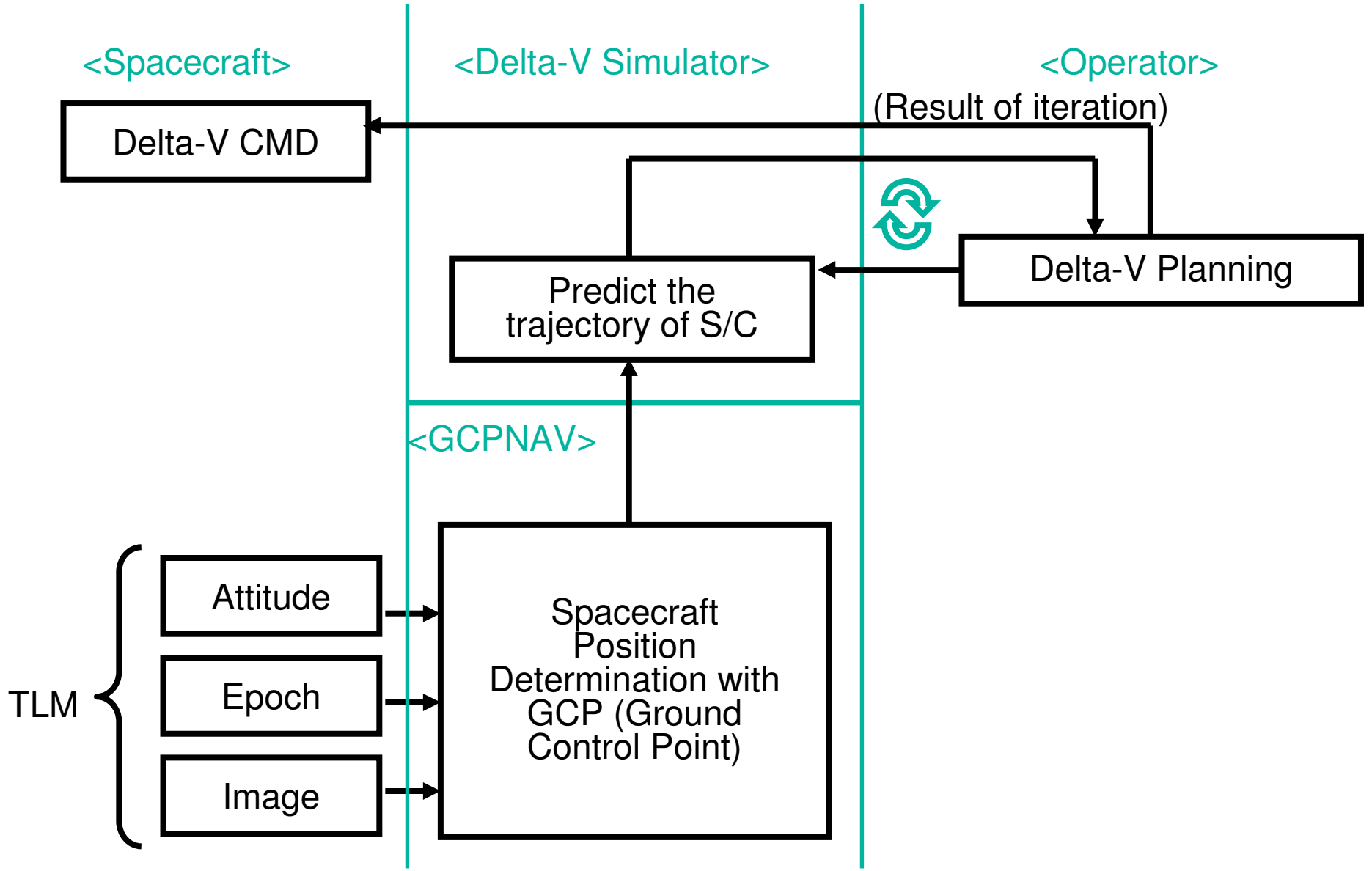
Newly Developed

Newly Developed

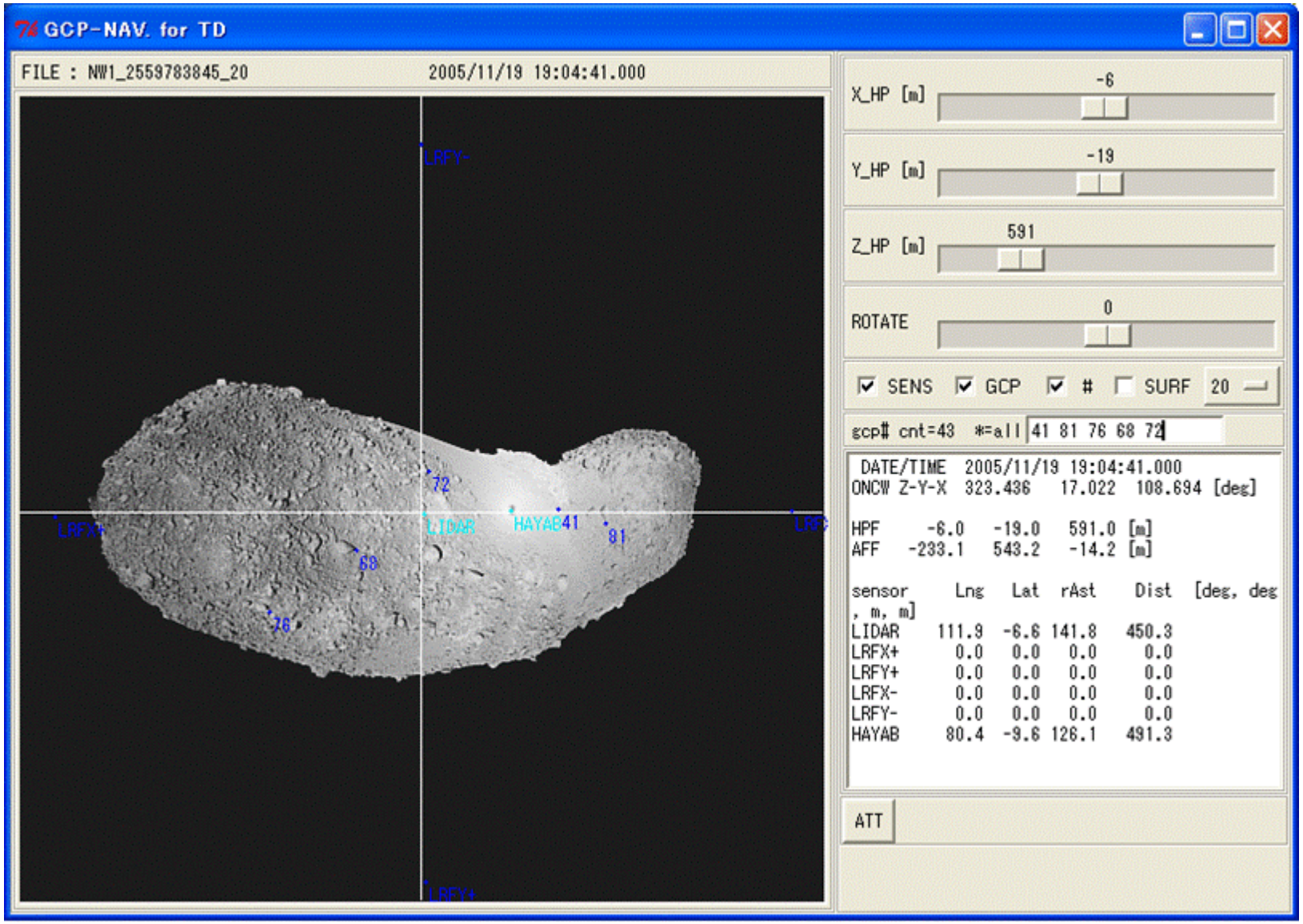




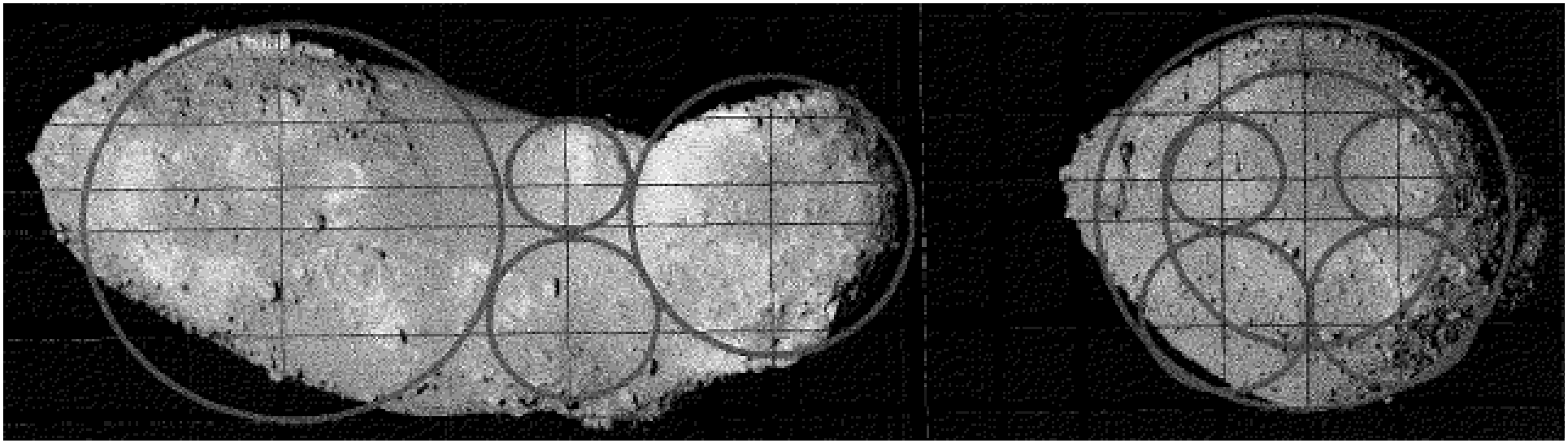
3-1 Operation with GCPNAV + Delta-V Simulator



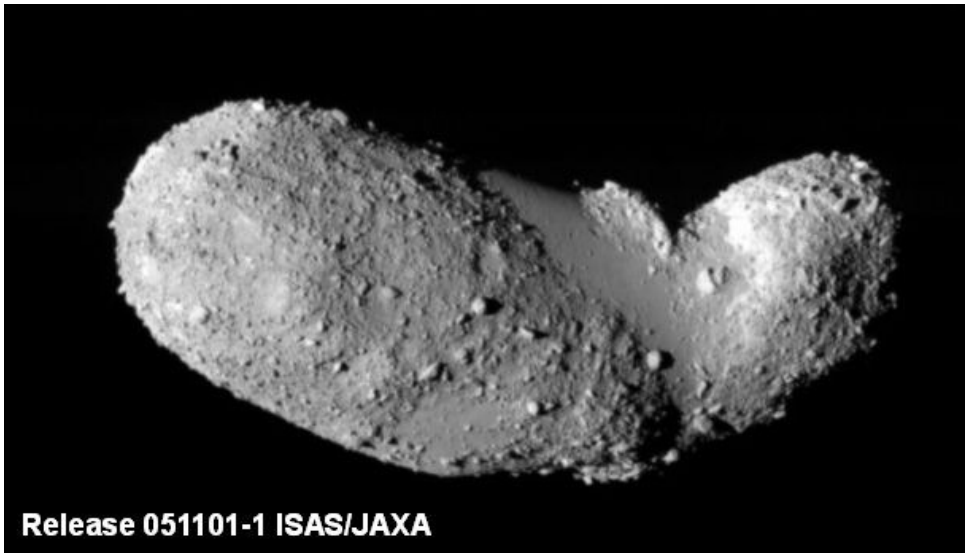
3-2 GCPNAV (Landmark matching)



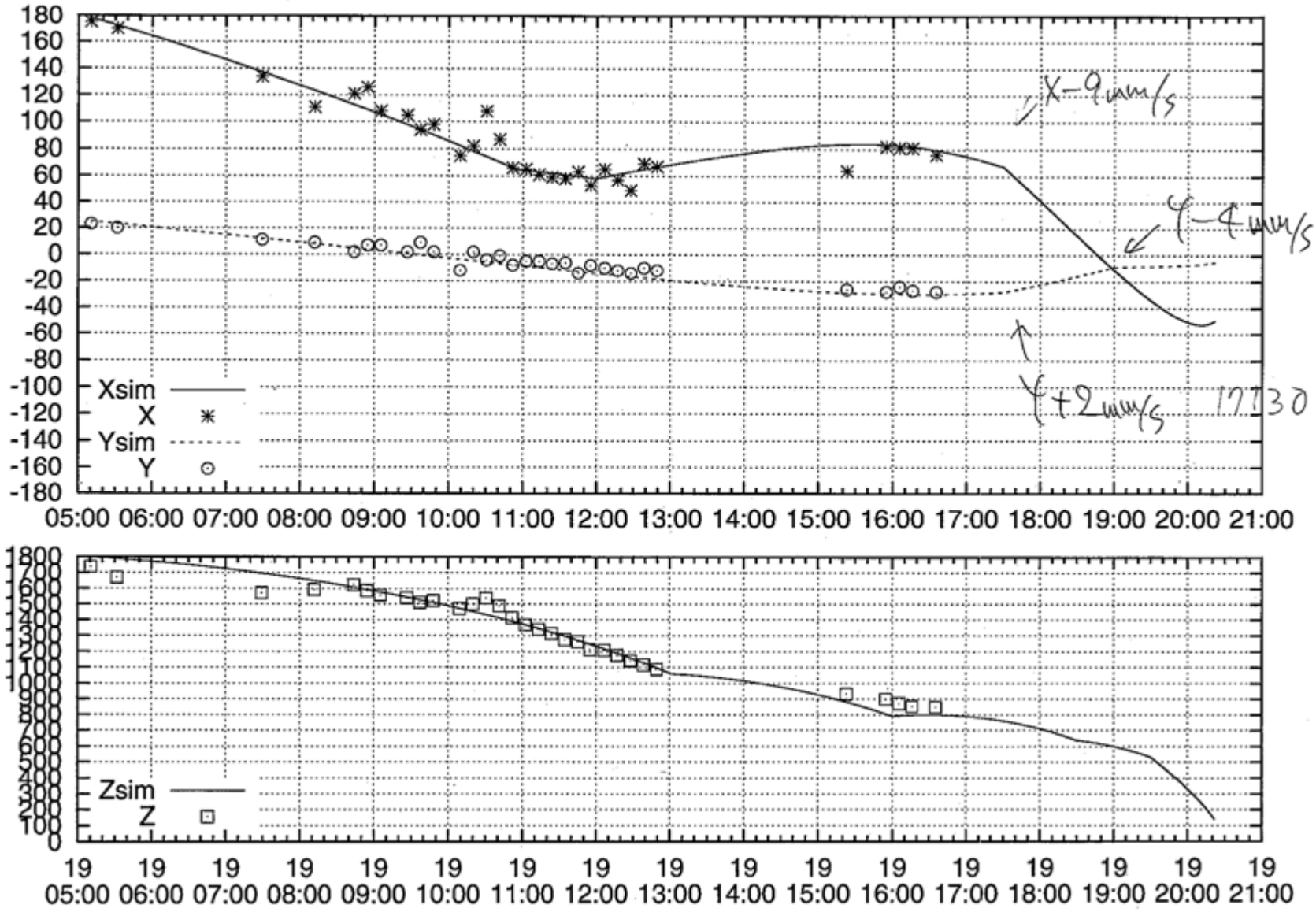
3-3 Six Points Mass Gravity Model for Delta-V Simulator



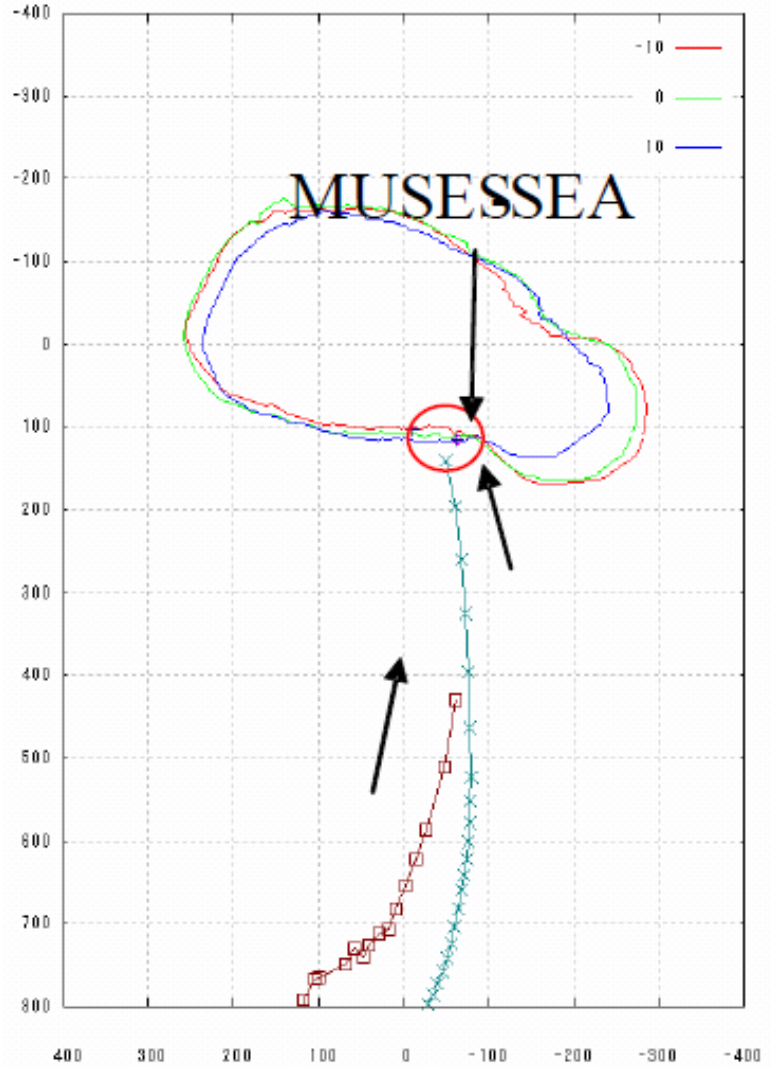
Each center of sphere is mass point.



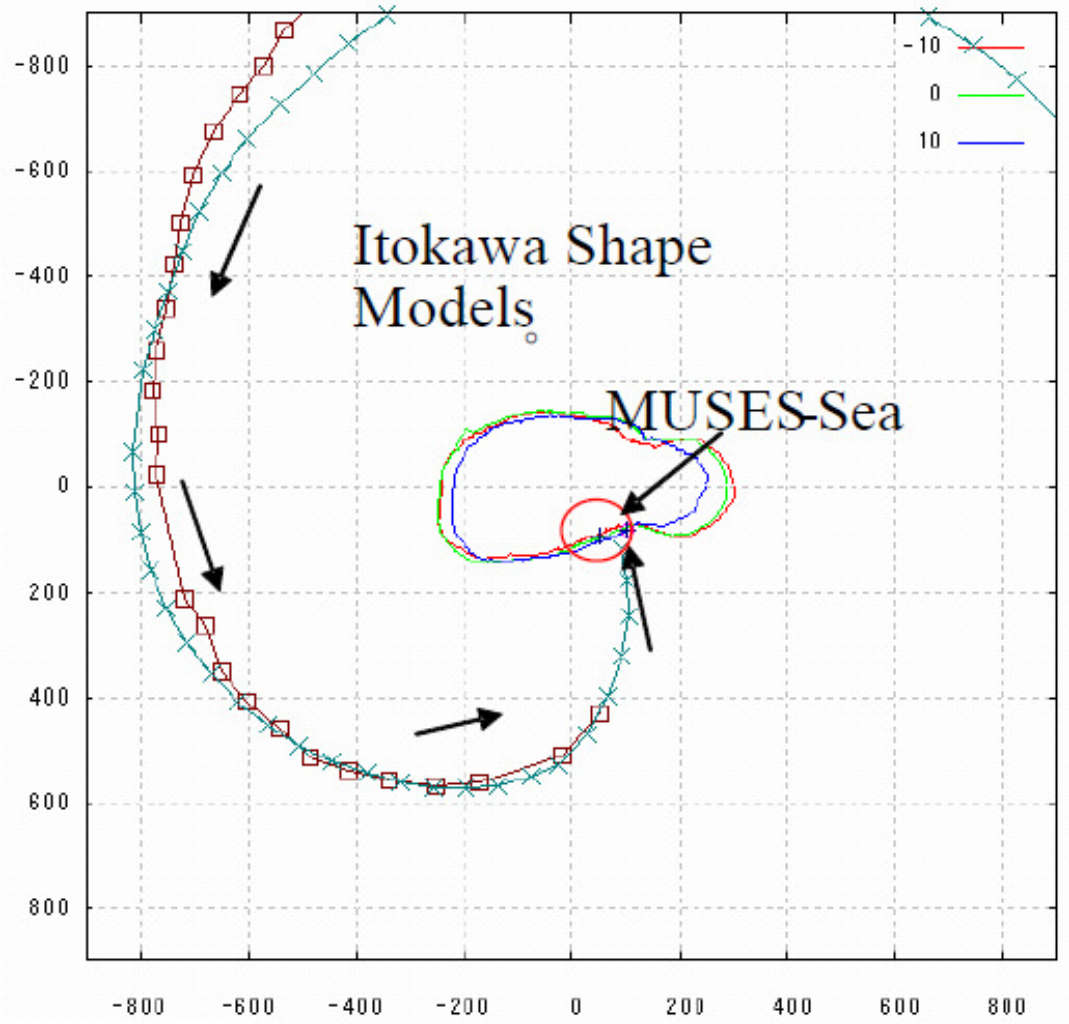
3-4 Output of GCPNAV and Delta-V Simulator (1st TD)



3-5 Planned and Actual Path (2nd Touch Down)



Semi-Inertial

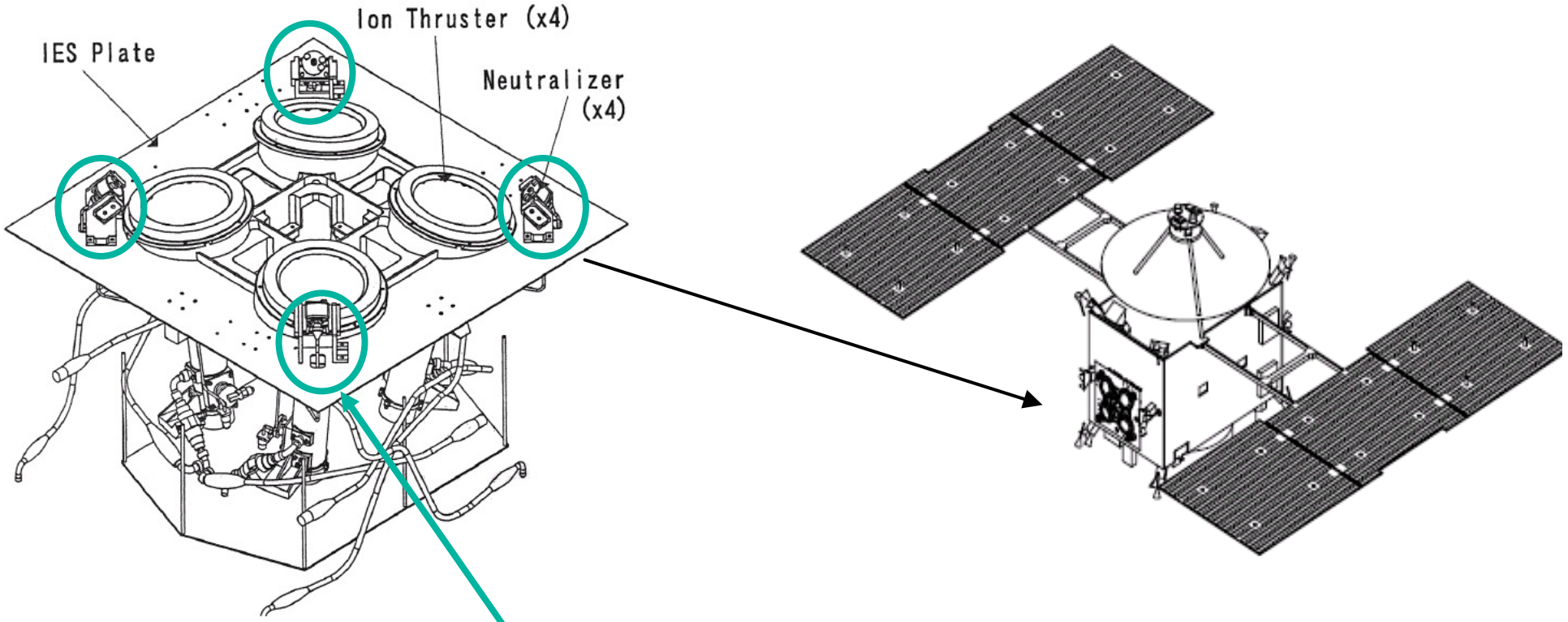


Itokawa-Fixed

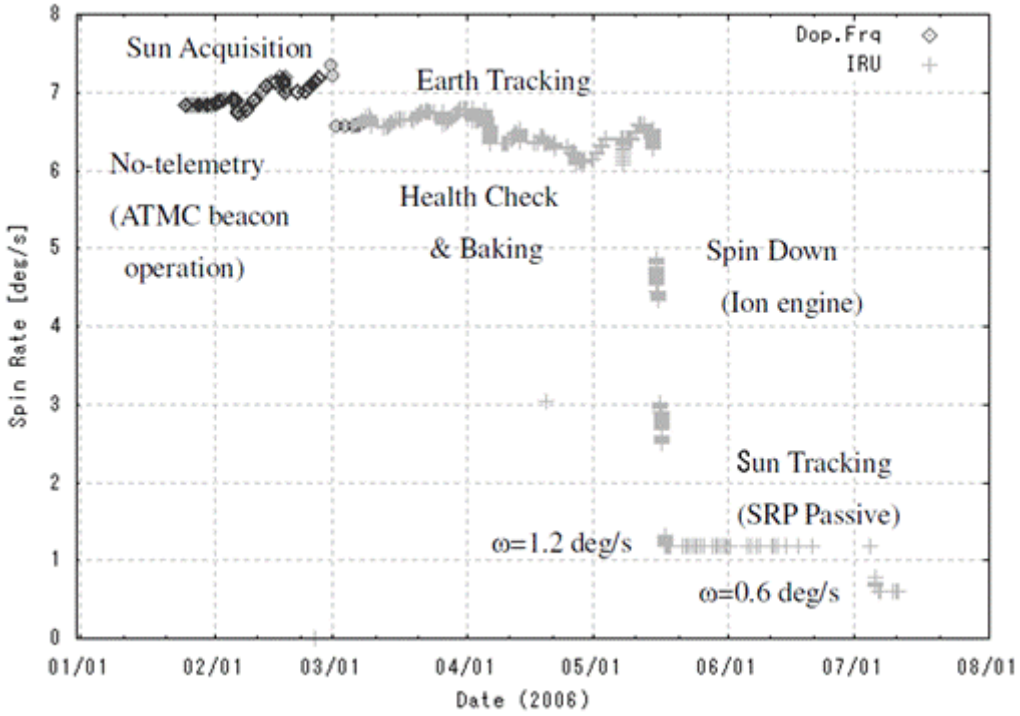
<No.4> RCS Leak

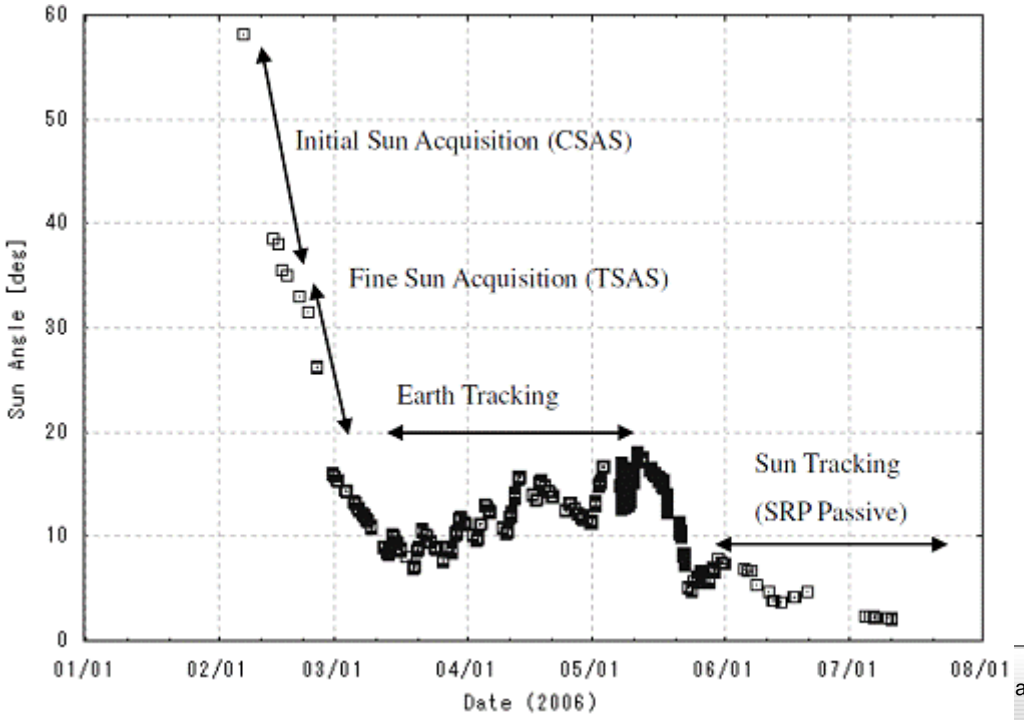
- Date: November 25th, 2005
- Cause: Unknown
- Results: Safe Hold Mode
- Recovery Method: Usage of Xe Gasjet and Solar Radiation Pressure
- Lessons Learned: Redundant system of RCS shall have independent pipes and heaters and shall be isolated thermally.

4-1 Ion Engines and Neutralizers on Spacecraft



Xe Gas outputted through Neutralizer produce 20uN.

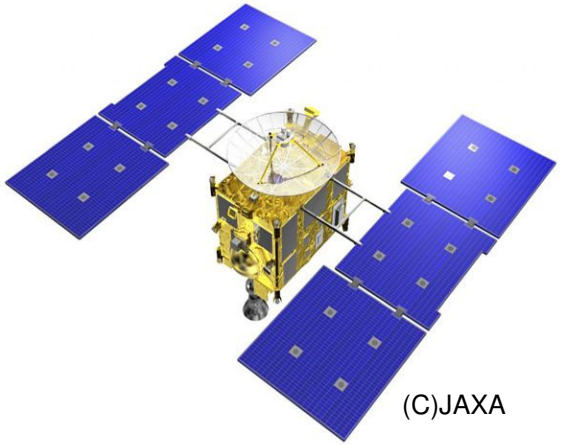




4-2 Attitude Control Results

- Initial Sun Acquisition
  - Coarse sun sensor
- Fine Sun Acquisition
  - Two dimensional sun sensor
- Ecliptic Acquisition
- Earth Acquisition
- IES Spin Down
- Sun Tracking using Solar Radiation Pressure

<No.5> Communication Down


(C)JAXA

- Date: December 8th, 2005
- Cause: RCS Leak
- Results: No downlink signal for 46 days
- Recovery Method: Short sweep and short command sending
- Lessons Learned: Prepare “Recovery Command”


(C)JAXA

5-1 Rescue Operation

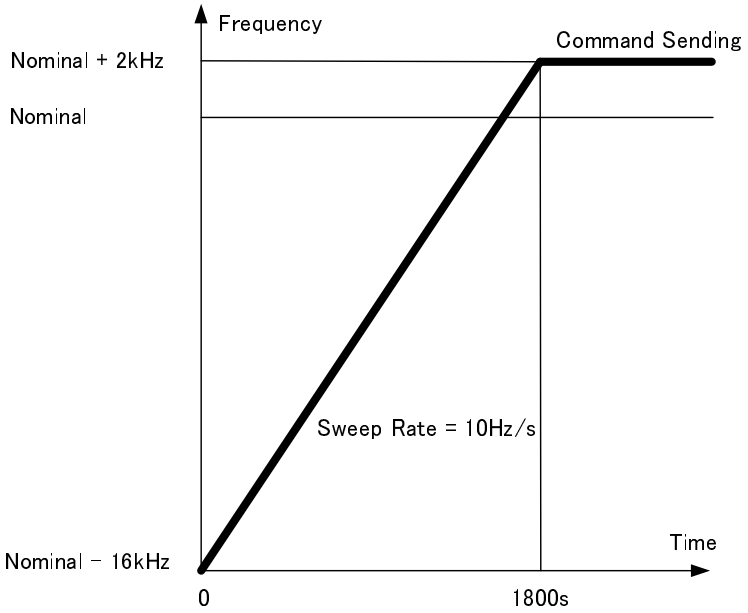


Fig.1 Command Sequence-1 (for AOS)

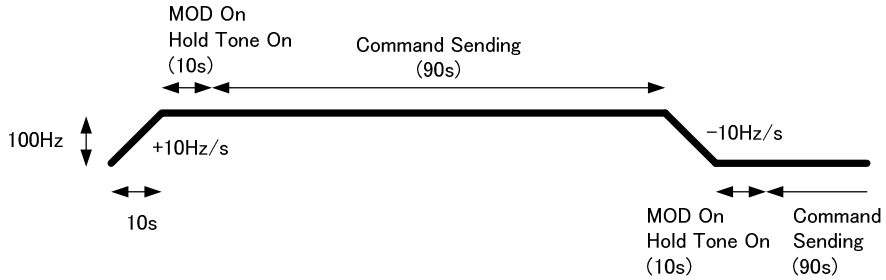


Fig.2 Command Sequence-2 (1/2)

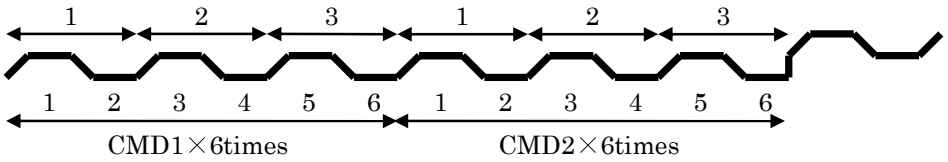


Fig.3 Command Sequence-2 (2/2)

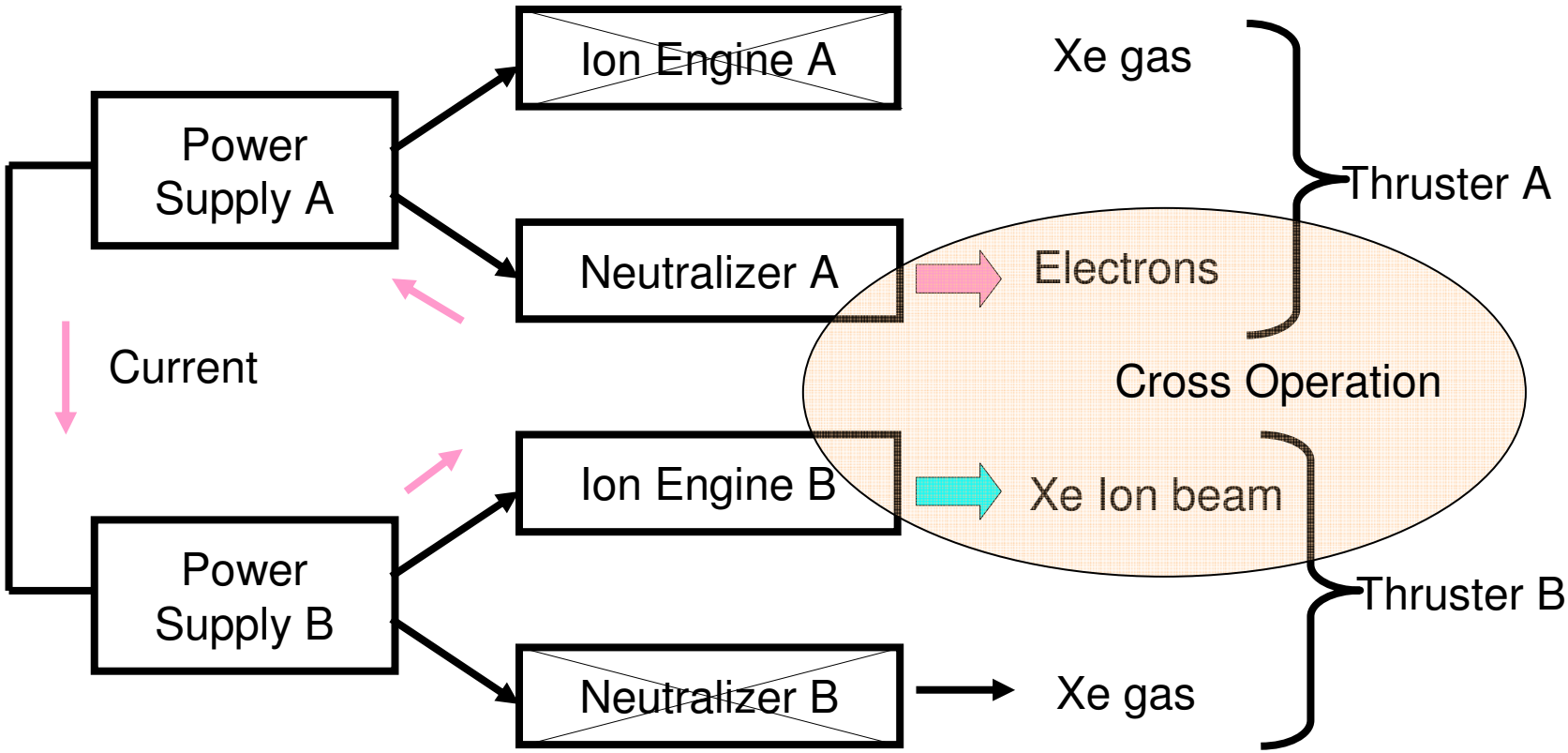
<No.6> BAT Over-Discharge

- Date: December 8th, 2005
- Cause: Attitude lost possibly caused by RCS leak
- Results: Fail of cell 1,2,3,4 (Total 11)
- Recovery Method: Charge of Cell 5-11 with small electric current
- Lessons Learned: Protect a BAT at the last moment of emergency.

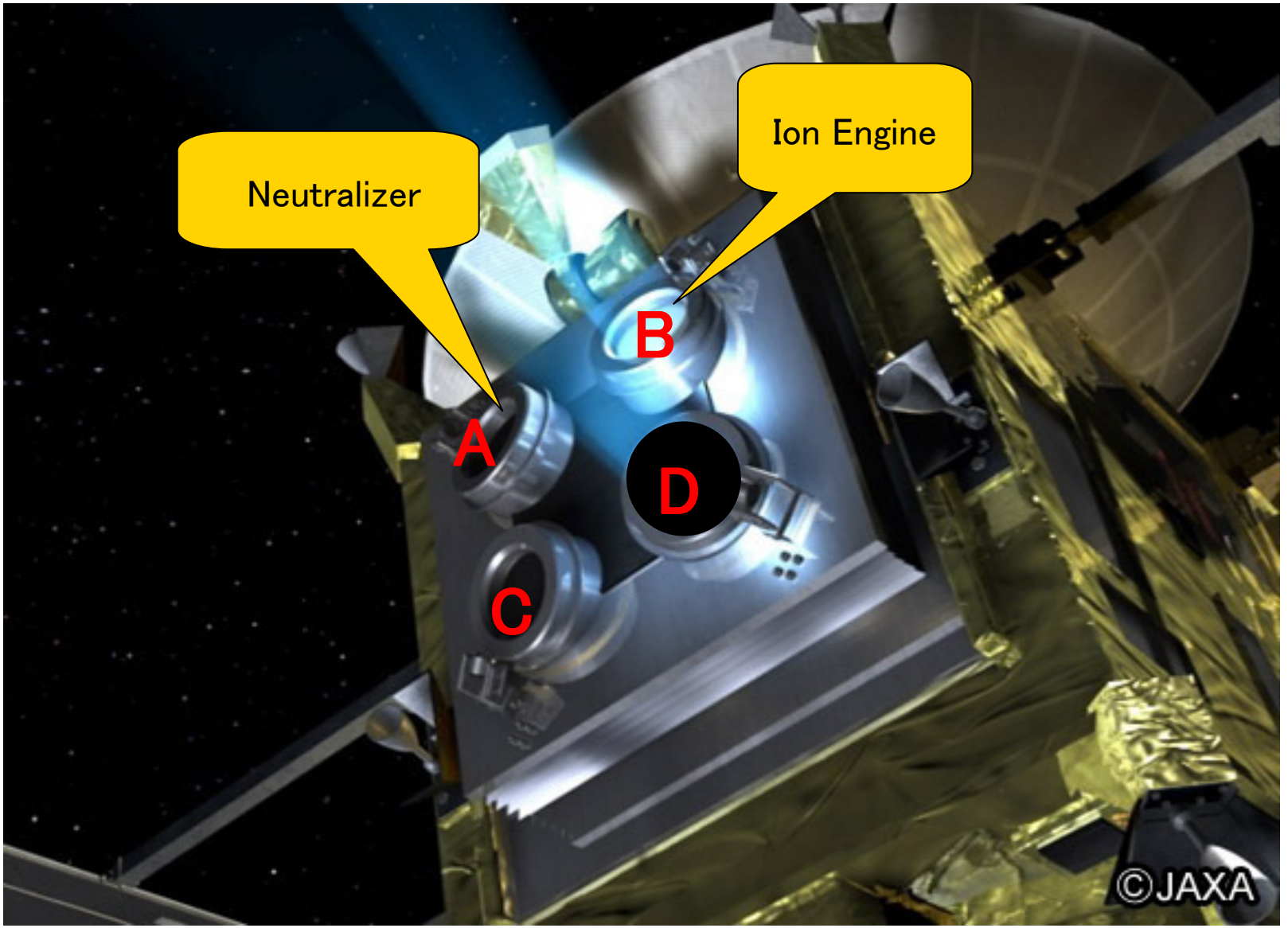
<No.7> Ion Engine System degradation

- Date: November 4th, 2009
- Cause: Too long run of IES operation
- Results: Almost all IES down
- Recovery Method: Cross operation of ITH-A neutralizer and ITH-B main engine
- Lessons Learned: Be prepared and have no regrets.

7-1 Cross Operation of Thruster A and B

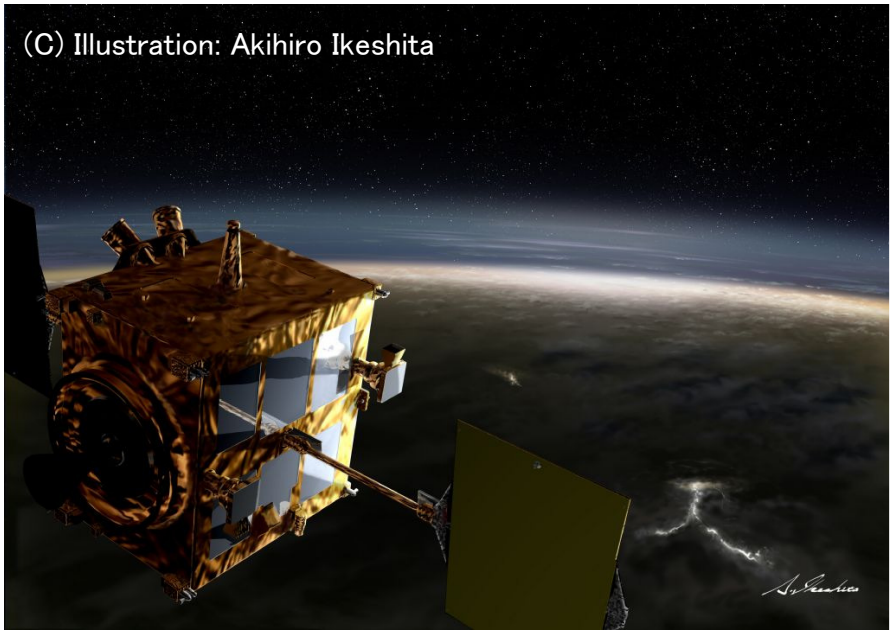


7-2 Cross Operation from November 13th, 2009



Lessons Learned : From Hayabusa to Akatsuki

1. “Improvement” shall be paid attention very carefully, even if it is minor.
2. Where there is a will, there is a way.
3. Strength of a compact and active team.
4. Redundant system of RCS shall have independent pipes and heaters and shall be isolated thermally.
5. Prepare “Recovery Command”.
6. Protect a BAT at the last moment of emergency.
7. Be prepared and have no regrets.



Akatsuki Design

- RW: Standard RW (No Aluminum Liner)
- RCS Plumbing is full redundant
  - Redundant plumbing root
  - Redundant heaters and temperature sensors
- BAT: At the last UVC (Under Voltage Control), BAT will be isolated.
- IRU: Same IRU, but all parts are lot assured by PCB level test.
- Operation Planning: EPNAV -> PCNAV
  - EPNAV (Electrical Propulsion Navigation) for Hayabusa
  - PCNAV (PLANET-C Navigation) for Akatsuki
- Used Heritage:
  - DHU (Data Handling Unit)
  - HCE (Heater Control Unit)

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